

### 2.1.3 Non-Metallic Conductors

We will just give a brief look at some especially important or useful **non-metallic conductors**:

#### Conducting Polymers

That polymers, usually associated with insulators, can be very good conductors was a quite unexpected discovery some **20** years ago (Noble prize **2001**). They always need some "**doping**" with ionic components, however.

The resistivity can be **exceedingly** low. e.g. for *Iodine (I) doped poly-acetylene (pAc)* we may have.  
 $\rho \leq 6,7 \mu\Omega\text{cm}$ .

Or in other words: If you divide by the density for some [figure of merit](#), it beats everything else, since  $\{\rho/\text{density}\}(\text{pAc}) > \{\rho/\text{density}\}(\text{Na})!$

More typical, however, are resistivities around **(10 ... 1000)  $\mu\Omega\text{cm}$** .

The conduction mechanism is along  $-\text{C}=\text{C}-\text{C}=\text{C}-$  chains, it is not yet totally clear. In fact, the first question is why this kind of chain is **not** generally highly conducting. [Use the link for the answer](#).

The conductivity is strongly dependent on "doping" (in the % range!) with ions, and on many other parameters, the [link](#) gives an example.

So do not confuse this with the doping of semiconductors, where we typically add far less than **1 %** of a dopant!

A new object of hot contemporary research are now **semiconducting polymers** which have been discovered about **10** years ago.

#### Transparent conductors

**Indium Tin Oxide (ITO)** (including some variations) is the only really usable **transparent** conductor with reasonable conductivity (around **1  $\Omega\text{cm}$** )! It consists of **SnO<sub>2</sub>** doped with **In<sub>2</sub>O<sub>3</sub>**.

**ITO** is technically **very important**, especially for:

- flat panel displays, e.g. **LCDs**.
- solar cells.
- research (e.g. for the electrical measurements of light-induced phenomena).

**ITO** is one example of conducting oxides, others are **TiO**, **NiO**, or **ZnO**. The field is growing rapidly and known as "**TCO**" = Transparent Conducting Oxides

If you can find a transparent conductor much better than **ITO** (which leaves a lot to be desired), you may not get the Nobel prize, but you will become a rich person rather quickly.

Since **In** is rare, and the demand is exploding since the advent of **LCDs**, you also would be a rich person if you invested in **In** some years ago.

#### Ionic conductors

Solid **ionic conductors** are the materials behind "**ionics**", including key technologies and products like

- Primary batteries.
- Rechargeable (secondary) batteries.
- Fuel cells.
- Sensors.
- High temperature processes, especially smelting, refining, reduction of raw materials (e.g. **Al**-production).

There is an extra module devoted to the [Li ion battery](#). This is important for you if you are interested in driving an affordable car in **20** years or so.

They are also on occasion the unwanted materials causing problems, e.g. in corrosion or in the [degradation of dielectrics](#).

See [Chapter 2.4](#) for some details about ionic conductors.

## Specialities : Intermetallics, Silicides, Nitrides etc.

**Silicides**, i.e. metal - silicon compounds, are important for microelectronics (**ME**) technology, but also in some more mundane applications, e.g. in heating elements. Some resistivity examples for silicides:

Silicide	MoSi <sub>2</sub>	TaSi <sub>2</sub>	TiSi <sub>2</sub>	CoSi <sub>2</sub>	NiSi <sub>2</sub>	PtSi	Pd <sub>2</sub> Si
$\rho$ ( $\mu\Omega\text{cm}$ )	40 ...100	38...50	13..16	10...18	$\approx$ 50	28...35	30...35

It looks like the winner is **CoSi<sub>2</sub>**. Yes, but it is difficult to handle and was only introduced more recently, like **NiSi<sub>2</sub>**. In the earlier days (and at present) the other silicides given above were (and still are) used.

Some more examples of **special conductors** which find uses out there:

Material	HfN	TiN	TiC	TiB <sub>2</sub>	C (Graphite)
$\rho$ ( $\mu\Omega\text{cm}$ )	30...100	40...150	ca. 100	6 ...10	1000

## Superconductors

Superconductors are in a class of their own. All kinds of materials may become superconducting at low temperatures, and there are neither general rules telling you *if* a material will become superconducting, nor at which *temperature*.

There will be an advanced module some time in the future.

**Why do we need those "exotic" materials?** There are two general reasons:

1. Because, if just **one** specific requirement exists for your application that is not met by common materials, you simply have **no choice**. For example, if you need a conductor usable at **3000 K** - you take **graphite**. No other choice. It's as simple as that.
2. Because **many** requirements must be met **simultaneously**. Consider e.g. **Al** for integrated circuits - there are plenty of important requirements; **see the link**. Since **no** material meets **all** of many requirements, an optimization process for finding an optimum material is needed.
- Al** won the race for chip metallization for many years, but now is crowded out by **Cu**, because in some figure of merit the importance of low resistivity in the list of requirements is much larger now than it was in the past. It essentially overwhelms **almost** all other concerns (if there would not be an almost, we would have **Ag**!).

## Questionnaire

Multiple Choice questions to 2.1.3